ANTARES System Design Options for Satellite-Based Air Traffic Management

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Abstract. The future European Air Traffic Management (ATM) System is currently being defined by the Single European Sky ATM Research (SESAR) programme. Iris is the European Space Agency programme to develop an Air-Ground communication system for the SESAR programme. Within the Iris Programme, ANTARES focuses on the development of a new satellite-based communication system based on the use of low-cost user terminals through the realization of a new satellite communication standard. The present paper describes the system design process defined and adopted in the ANTARES project to cope with the uncertainties of the user requirements The proposed process is based on the definition of System Architecture Options allowing to evaluate the impact of requirements variability on the satellite system design. Each System Architecture Option will implement a set of Design Options which are system or technology solutions adopted to design the system or its elements. An insight on the Design Option relevant to the airborne user terminal features is provided in the paper.

Keywords: ANTARES, L-Band, ATM, SESAR, System design options.

1 Introduction

The need of a dual link to support air-ground communication in high-density continental airspace has been recognized of key importance by the Single European Sky ATM Research (SESAR) working groups. This dual link will rely on two separate means of communication to avoid common points of failure; one link relies on a new terrestrial line-of-sight technology in L-Band (LDACS), while a satellite communication system will also provide communication services over high-density continental areas to ensure the required availability.

Iris is the European Space Agency (ESA) programme to develop a new Air-Ground communication system for Air Traffic Management (ATM) as the satellite-based communication solution for the SESAR programme. The system design Phase B of the Iris Programme is called ANTARES (AeroNauTicAl REsources Satellite based) and has started in November 2009. ANTARES will contribute to the modernisation of ATM by providing more efficient connections for digital data to cope with the growing amount of information required and the increasing number of users.

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The general ANTARES system architecture is depicted in Fig. 1 which highlights the physical system components – i.e. the space segment, the user terminals segment and the ground segment – along with the communication standard, including the whole set of system functionality (from the physical layer up to the network layer of the protocol stack) allowing the communication between system components with a given level of performance. The interfaces with the external European ATM (EATM) system are also depicted.

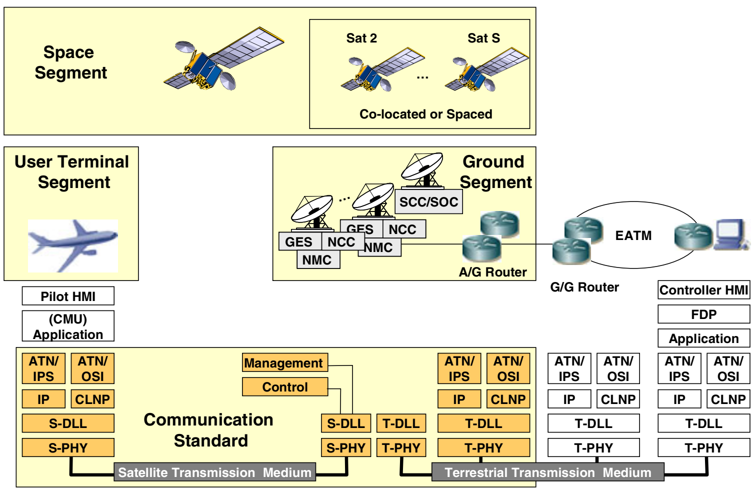

Fig. 1. ANTARES General System Architecture. In the figure above are depicted the network architecture consists of the mobile terminal, lo space segment e in ground segment comprendente le ground earth stations (GESs), the Satellite Control Centre (SCC), the Satellite Operation Centre (SOC), the Network Control Center (NCC) and the Network Management Centre (NMC). Under the respective protocol stack. It is possible identify the Physical layer (PHY), Data Link Layer (DLL), the Connectionless Network Protocol (CLNP), the Internet Protocol (IP) under the Aeronautical Telecommunication Network (ATN) both for Internet Protocol Suite (IPS) and Open System Interconnection (OSI). The stack go up to the Communications Management Unit (CMU), Foundry Discovery Protocol (FDP) for the pilot and controller respectively.

The ANTARES end-to-end system architecture has been defined by identifying the set of functionality to be supported, by allocating them to the physical elements and by suitably dimensioning the overall system so as to provide services to the estimated population of aircrafts with the required performance.

The ANTARES system aims at meeting a set of requirements which are generated by ESA considering (among others) the activities currently ongoing in the context of SESAR Joint Undertaking (JU) and the baseline for applications and communication performance defined in the FAA/Eurocontrol COCR (Communication Operating Concept and Requirements for the Future Radio System) [7]. Since these activities are running in parallel to the ANTARES project, some key requirements and their flow-down to the satellite communication system are not firmly defined yet. This entails that an uncertainty is still present in key requirements for the some specific areas such as:

1. Security: both information security and transmission security.
2. Number and type of applications/services.
3. Number of equipped aircraft as function of time.
4. Service provider configuration and associated ground segment architecture
5. User terminal performance which are achievable considering airframes installation constraints and available technologies as for high power amplifier and antenna etc.

In order to cope with these uncertainties, a systematic process has been defined by ANTARES system team to provide an understanding of the impact of the variability of key requirements on the satellite communication system design.

The proposed process is based on the concept of Requirement Options corresponding to different "interpretations" of the user requirements. In particular, a Requirement Option is defined as any combinations of attributes, i.e. technical variables which are used in order to qualify a given system feature.

Different system architectures may be defined by suitably combining the different alternatives of each Requirement Option. Even though a wide set of theoretical system architectures can be generated by these combinations, a subset of five alternative system architectures has been selected which is highly representative and particularly appropriate to evaluate the impact of requirements variability on the system design. This set of alternatives has been used for system dimensioning and specifications and each of the alternatives has been analyzed, dimensioned, specified and assessed on the basis of suitably selected figures of merit. The final result of this design process is that a system architectures "catalogue" is offered by the ANTARES project which includes five solutions with five complete sets of system and segment specifications each of them suitably assessed. The most suitable solution will be selected by operators and aeronautical stakeholders. As such, the ANTARES architecture depicted in Fig. 1 provides a general view of the system and a specific System Architecture Option is obtained by particularising this figure with the identified system choices.

As highlighted above, the Requirement Options are used in ANTARES in order to cope with uncertainties of requirements which are outside the ANTARES boundaries and therefore not under the control of the ANTARES team. Moving within the ANTARES system perimeter, the system design has been performed by identifying a wide set of possible Design Options (more than thirty) representing different technical choices which can be made to design the system or its elements and which are entirely under the definition and responsibility of the ANTARES team. All these Design Options have been analyzed and duly traded-off so as to produce the most appropriate technical solutions which are reflected in the system technical specifications and design.

Considering the user requirements relevant to the need to have very small user terminals on board aircrafts, which are devised so as to minimize the equipment weight, size, power dissipation and costs, it is worth pointing out that key Design Options refer to the user terminal features.

Several options have been investigated as for the number of user terminal antennas (single antenna or dual antenna with different inclination angles with respect to air-frame body) taking into account their installation positions on the aircraft and their performance as well as the radiofrequency performance of the high power amplifier.

The present paper aims at describing the system design process for the definition of the ANTARES System Architecture Options and the selection of the system baseline. Moreover, an insight on the trade-off performed on the user terminal configurations is provided. In particular , the paper is organised as follows. The present section is devoted to introduce the main concepts to understanding the proposed system design process. Section 2 gives guidelines for the ANTARES system design process, focused on the Requirement Options and on the *System Architecture Options*. Requirement Options have been specifically distinguished from *Design Options,* shown in the Section 3 that will focus on the user terminal capability to maintain link during aircraft manoeuvring.

2 System Design Process

In order to cope with the uncertainties of the user requirements which are currently being defined in activity running in parallel to the ANTARES project, a systematic process has been defined by ANTARES system team to provide an understanding of the impact of the variability of the key requirements on the satellite communication system design. The proposed process is schematically depicted in Fig. 2 and consists of the following steps:

- Step 1:
  - Definition of the Requirement Options (ROs).
  - Definition of the System Architecture Options (SAOs) from all the combinations of the Requirement Options.
  - Definition of the Figures of Merit (FOMs) for the quantitative evaluation of the System Architecture Options.
- Step 2:
  - Identification of a reduced number of System Architecture Options.
- Step 3:
  - Analysis and design of the system configurations associated with the System Architecture Options identified in the Step 2.
- Step 4:
  - Quantitative assessment of the alternative System Architecture Options identified in the Step 2 and designed in the Step 3 on the basis of the Figures of Merit identified in the Step 1.
- Step 5:
  - Selection of the baseline System Architecture Option.
  - Identification of the set of baseline Requirement Options associated with the baseline System Architecture Option.

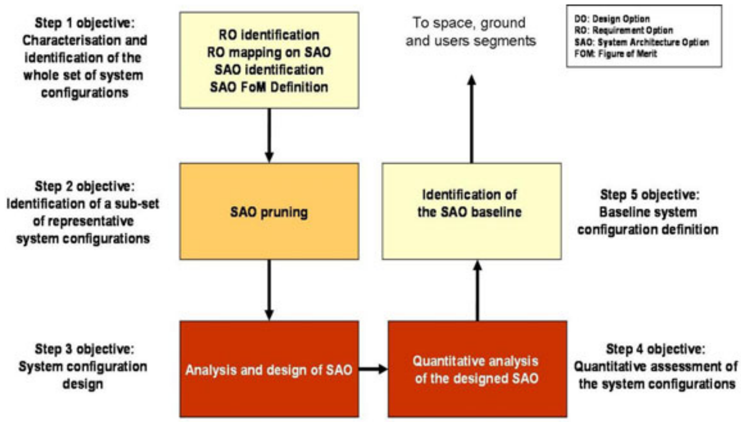

Fig. 2. Requirement Option Baseline Identification Overall Process

2.1 Requirement Options Definition

The Requirement Options are adopted in order to cope with the uncertainties of user requirements. As such, they correspond to different "interpretations" of the user requirements. In particular, a Requirement Option is defined as any combinations of attributes, i.e. technical variables which are used in order to qualify a given system feature. The ANTARES Requirement Options are presented in the Table 1.

Table 1. ANTARES Requirement Options Definitions

Requirement Options		Requirement Option Definition
RO1	**Information and Communication Security (INFOSEC/COMSEC)**	Information security and communications security capabilities that are applied within the ANTARES system boundaries in order to mitigate the threats on informatics system and on communication devices or other electronic systems. The attributes of RO1 are determined by the results of the threat analysis.
RO2	**Transmission Security (TRANSEC)**	Transmission security capabilities that are applied within the ANTARES system boundaries, in order to mitigate the threats deriving from RF interference sources that may affect the user plane for the provisioning of the AOC and ATC services, the control plane and the management plane.
RO3	**System Capacity**	Information volume (Mbps) entering the ANTARES System at network layer.
RO4	**End User Terminal Capability**	Radiofrequency transmission performance (EIRP) of the end user terminal on-board the Satcom equipped aircrafts.
RO5	**Ground Segment Architecture**	Topology of the ground segment architecture.

2.1.1 Requirement Option on INFOSEC/COMSEC (RO1)

This Requirement Option refer to the system capabilities aiming at mitigating the general threats and attacks to the ANTARES system and applying on the different interfaces such as the satellite air interface between GES and AES, the communication interfaces between elements of the ground segment (GES, NCC, NMC, SOC/SCC etc.), the telecommand and telemetry interfaces.

Three attribute values have been defined for this Requirement Option based on different security implementation "levels":

- NULL refers to the case that INFOSEC/COMSEC mechanisms are implemented neither in the EATMN and nor by ANTARES (a part those to guarantee integrity);
- LOW refers to the case that satcom-specific authentication and integrity mechanisms are implemented by ANTARES;
- HIGH refers to the case that a full set of INFOSEC/COMSEC mechanisms are required to be implemented by ANTARES;

The following table describes the specific feature of the ANTARES system linked to the Requirement Option:

Table 2. Attributes and Values for the Requirement Option on INFOSEC/COMSEC

Attribute	Attribute Definition	Attribute Logical Value		
		NULL	LOW	HIGH
Confidentiality	Transmitted data are not disclosed to unauthorized entities or process	NO	NO	YES
Integrity	Messages are received with no modification. Data are not accidentally or maliciously modified, altered or destroyed	YES	YES	YES
Authentication	The identity of the entities involved in a communication is verified	NO	YES	YES
Access Control	The users privilege to access the resources of a system is granted only to authorized users, programs, processes, or other systems	NO	NO	NO
Non repudiation	The transmitter or the receiver is not allowed to deny its acts	NO	NO	NO

2.1.2 Requirement Option on TRANSEC (RO2)

This Requirement Option refers to the system capabilities supporting the ANTARES transmission security. Two attributes have been defined to cover two extreme cases corresponding two possible levels of immunity against known and unknown interference:

- LOW, entails that the ANTARES system is robust only to interferences from known equipment, as for coordination and design results in front of possible inter-system and intra-system interference sources (non malicious).
- HIGH entails that the ANTARES system is robust to interferences from both known and unknown equipment; this case covers the case of malicious jammers on the ATM satellite system.

As far as the immunity against known equipment interference, the Ku-band uplink the level of immunity to interference has been dimensioned considering the following two categories of interference sources:

- Out-of-band/spurious emissions from earth stations belonging to other satellite systems, according to the normative documents [1] and [2].

- Off-axis EIRP emission density within the band from earth stations belonging to adjacent satellite systems, transmitting within the band of interest (14-14.25 GHz), according to the normative documents [2] and [3].

For the Ku-band downlink, the level of immunity to known interference has been dimensioned considering the following two categories of interference sources:

- Out-of-band/spurious emissions from other satellite systems, according to [4]
- In-band emissions from adjacent satellite system, transmitting within the band of interest, according to [5].

For the L-band user up-link, the known interference on the ANTARES uplink frequency band due to the out-of-band emissions generated by other terminals has been evaluated by assuming as reference the normative documents [6].

The level of immunity against unknown equipment interference (both intentional and unintentional) has been evaluated in terms of possible thresholds for the acceptable I/S levels, where I indicates the interfering signal and S is the useful signal. The following cases have been considered as for the user uplink

- unknown, out-of-band interference where out-of-band indicates bands externals to the 10MHz bandwidth allocated to the aeronautical services.
- unknown in-band, out-of-channel interference where in-band indicates the 10MHz bandwidth allocated to the aeronautical services and out-of-channel means that the interference is not overlapped to the ANTARES system carrier.
- unknown, in-band, in-channel interference where in channel means that the interference is overlapped to the ANTARES system carrier

In any case, the telecommand and telemetry link will be protected from possible intentional and unintentional jammers by means of spread spectrum-based technique.

2.1.3 Requirement Option on System Capacity (RO3)

This Requirement Option is to provide a range of capacity values (i.e. offered load) within which the satellite communication system shall be designed. Table 1 defines three attributes of the Requirement Option and relates these attributes to the reference traffic scenarios they are associated with, considering the implications of both the growth of air traffic in the reference time frame and the applications being considered). The described reference traffic scenarios have been defined on the basis of the aircraft traffic profiles analyses performed in the context of the ANTARES framework. In this respect, several aircraft traffic profiles have been considered

Table 3. Attributes and Values for the Requirement Option on System Capacity

Attribute	Reference scenarios	Attribute Value (capacity)
ANTARES system traffic capacity	Low capacity scenario	FWD=0.6 Mbps RTN=0.34 Mbps
	Medium capacity scenario	FWD=2.3 Mbps RTN=0.4 Mbps
	High “plus” capacity scenario	FWD=4.65 Mbps RTN=0.75 Mbps

corresponding to different traffic growth rates for the predictions. Both the Air Traffic Services (ATS) and Aeronautical Operational Control (AOC) applications defined in [7] have been considered to dimension the overall data traffic over the ECAC.

2.1.4 Requirement Option on User Terminal Capability (RO4)

The attributes of this Requirement Option refer to two different cases of aeronautical user terminal design: one with "low performance" and one with "high performance". The different levels of user terminal performance have been quantified in terms of possible sizes of the airborne power amplifier, which may provide:

- 20W saturated power.
- 40W saturated power.

In both cases it is assumed that the user terminal should be designed so as to minimise the impact onto the aircrafts as for the installation. In this respect, the possibility to support nominal operational modes of the user terminal without need for active cooling is pursued as a key factor to reduce the above mentioned installation impacts.

These two cases are identified as representative of user terminal classes which may be installed on different typologies of aircrafts.

Analyses (e.g. link budgets, thermal analysis etc.) have been performed considering the actual operating point of the amplifier, taking into account the required output back-off (OBO) and the relevant physical losses due to installation constraints.

2.1.5 Requirement Option on Ground Segment (GS) Architecture (RO5)

This Requirement Option refers to the topology of the ground segment architecture. The ground segment elements considered to define this topology are:

- Ground Earth Station (GES).
- Satellite Service Provider (SSP).

Depending on both the number of GESs and SSPs, two different classes of ground segment topologies can be identified, which are captured by the attributes defined for this Requirement Option and listed in Table 4:

- Centralised, entails a topology which is fully centralised as for distribution of the physical elements and relevant functions.
- Decentralised, entails a topology presenting a certain level of decentralisation of the physical elements and/or relevant functions. The level of decentralisation may vary depending on the combination of attribute values.

Table 4. Requirement Option 5 (GS Architecture)

Attribute	Attribute Definition	Attribute Logical Value	
		Centralised	Decentralised
Number of SSP	Number of providers providing the SatCom service to the Communication Service Provider(s) (CSP)	1	3
Number of GES	Number of stations providing the Tx/Rx communication capability	1	15

2.2 System Architecture Options

By combining the Requirement Option values described in the previous section up to forty-eight System Architecture Options (SAO). These options are only theoretical. In practice, only System Architecture Options which are useful to highlight the impact of requirements variability need to be studied. In this respect, a subset of five alternative system architectures has been selected which is highly representative and particularly appropriate to evaluate the impact of requirements variability on the system design. They are defined as follows:

- System Architecture Option 1:
  - Supporting a low capacity traffic (RO3=LOW)
  - Presenting high resistance to the interference (RO2=HIGH)
  - Not implementing any specific information/communication security mechnisms (RO1=NULL)
  - Having a decentralised GS architecture (RO5=DECENTRALISED)
- System Architecture Option 2
  - Supporting a medium capacity traffic (RO3=MEDIUM)
  - Presenting high resistance to the interference (RO2=HIGH)
  - Not implementing any specific information/communication security mechanism (RO1=NULL)
  - Having a decentralised GS architecture (RO5=DECENTRALISED)
- System Architecture Option 3
  - As SAO 2, but with a centralised GS architecture (RO5=CENTRALISED)
- System Architecture Option 4
  - Supporting a medium capacity traffic (RO3=MEDIUM)
  - Presenting high resistance to the interference (RO2=HIGH)
  - Implementing specific information/communication security mechanisms (RO1=HIGH)
  - Having a decentralised GS architecture (RO5=DECENTRALISED)
- System Architecture Option 5
  - Supporting a very high capacity traffic (RO3=HIGH+)
  - Presenting high resistance to the interference (RO2=HIGH)
  - Not implementing any specific information/communication security mechanisms (RO1=NULL)
  - Having a decentralised GS architecture (RO5=DECENTRALISED)

As far as the Requirement Option on user terminal capabilities (RO4) is concerned, it may be observed that the two categories of UT performance will not drive the final choice on the system architecture. They may be regarded as proposed options to be selected on the basis of on aircraft installation constraints, operational conditions etc.

The above defined set of alternatives has been used for system dimensioning and specifications and each of the alternatives has been analyzed, dimensioned and specified. The final result of this design process is that a system architectures "catalogue" is offered by the ANTARES project which includes five solutions with five complete sets of system and segment specifications each of them suitably assessed. The most suitable solution will be selected by operators and aeronautical stakeholders. The system architecture in Fig. 1 include all the possible System Architecture Options which may result from the Requirements Option combination. A specific System Architecture Option is obtained by particularising this figure with the identified system choices.

2.3 Figure of Merit of System Architecture Options

The System Architecture Options are compared on the basis of a set of of quantitative variables aiming at capturing technical and programmatic elements.

These quantitative variables, also referred to as Figures of Merit (FOMs), are:

1. Cost of the user terminal (UT), including:
   - Cost for UT development.
   - Cost for installation and maintenance.
2. Cost of the overall system, including
   - Nonrecurring and recurring costs for space segment development (payload and platform).
   - Nonrecurring and recurring costs for ground segment development.
   - Cost for redundancy
   - Cost for launch
3. Cost of system operations, including:
   - Operational costs for the Satellite Operator relevant to in-orbit tests, payload monitoring and control, station keeping procedures execution, satellite relocation (if necessary), data archiving and retrieving, personnel and maintenance of the SCC and SOC etc.
   - Operational costs for the Satellite Service Provider (SSP) relevant to satellite bandwidth and resources procurement, personnel and NMC and NCC operations, maintenance of the SCC and SOC etc.
4. Spectrum (i.e. amount of required bandwidth).
5. System margins

3 Design Options

The Requirement Options have been introduced in ANTARES in order to cope with uncertainties of requirements which are outside the ANTARES boundaries and therefore not under the control of the ANTARES team.

Moving within the ANTARES system perimeter, the system design has been performed by identifying a wide set of possible Design Options (more than thirty) representing different technical choices which can be made to design the system or its elements and which are entirely under the definition and responsibility of the ANTARES team. All these Design Options have been analyzed and duly traded-off so as to produce the most appropriate technical solutions which are reflected in the system technical specifications and design.

A key requirements coming from the aeronautical stockholders is to have very small user terminals on board aircrafts. As a consequence, user terminal shall be devised so as to minimize the equipment weight, size, power dissipation and costs.

Toward this end, key Design Options has been defined which refer to the user terminal features. The following section focused on these several options.

3.1 Design Option on Single vs Multiple Antenna on Board the Aircraft

This DO aims at analysing, quantitatively evaluating and trading-offs the possible solutions to provide the required link availability, during aircraft manoeuvring and in particular banking and pitching. Several options have been investigated.

During the en-route phases of the aircraft, it is highly probable that the radio link between the aircraft user terminal and the satellite has line-of-sight characteristics, since no impairments are supposed to be interposed between the antennae. Nevertheless it is possible that, during aircraft manoeuvring (bank angle 35°) and for specific relative position between aircraft and satellite (especially at high latitudes / low satellite elevation angles ~5°), that the line-of-sight is lost. Fig. 3 shows examples of the UT antenna gain variation due to aircraft manoeuvring.

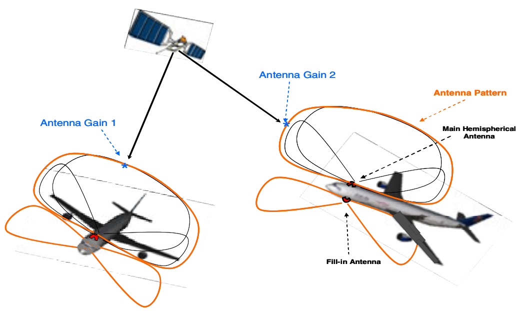

Fig. 3. User Terminal Antenna Gain Variation due to Aircraft Manoeuvring

The following implementation alternatives are considered for this DO:

- Alternative 1: Aircraft user terminal with single antenna (Reference).
- Alternative 2: Aircraft user terminal with two antennas located ~45 deg away from top of the fuselage on both sides.
- Alternative 3: Aircraft user terminal complemented by fill-in antenna.

The trade off among the different option has been based on (among others) link budget performance, antenna radiation pattern and geometrical link visibility analysis.

3.1.1 Trade-Off Criteria

The considered trade-off criteria for the evaluation of DO alternatives are:

- Geometrical availability of the link: the higher this availability, the higher the overall service availability provided the link margin is sufficient. This criterion is quantified by the percentage of time the satellite is visible over a statistical population of aircraft flight trajectories, i.e.

$$T_{\%} = \frac{\sum_i \sum_j t_{i,j}^{vis}}{\sum_i t_i^{vis}} \tag{1}$$

where:

$t_{i,j}^{vis}$ =time duration of *j*-th visibility period of the *i*-th aircraft flight trajectory.

t_i = time duration of the *i*-th aircraft flight trajectory.

$i \in$ [Set of aircraft flight trajectories].

$j \in$ [Set of visibility periods].

- Implementation feasibility: e.g. compatibility with aircraft installation constraints. This is a fundamental factor for acceptability of the Satellite Communication System overall. This criterion is quantified by the number of antennas installed on the aircraft, taking into account redundancy.
- Overall link margin at max banking angle. This parameter, together with the geometrical visibility defines the service availability during manoeuvring. This criterion is quantified by means of the margin of the signal-to-noise ratio variation with respect to the single antenna case:

$$\Delta\left(\frac{C}{N_{0,t}}\right)=\left(\frac{C}{N_{0,t}}\right)-\left(\frac{C}{N_{0,t}}\right)_{Single\ Antenna} \quad (2)$$

3.3 Trade-Off Justification and Conclusions

The quantitative assessment for the identified alternatives is reported in Table 5. The trade-off is based on two major analyses whose major results are briefly reported in the following:

- Link geometrical visibility analysis.
- Link budget analysis.

A third analysis has been performed on the antenna radiation, taken into account in the link budget analysis but are not explicitly reported in the following.

Table 5. DO Quantitative Assessment

Evaluation Criteria	Comment / Explanation		DO Quantitative Assessment: AES with Single Antenna	AES with two Antennas (at 45°)	AES complemented
Geometrical availability of the link	% of time the satellite is visible over a statistical population of aircraft trajectories= (1)		Airliner: 9999910747% Civil utility aircraft: 9998338439%	Airliner: 9999925334% Civil utility aircraft: 9998956203%	Airliner: 9999982938% Civil utility aircraft: 9999262673%
	Max Outage Time Occurence Duration		Airliner: 6.042 sec Civil utility aircraft: 67.885 sec	Airliner: 6.486 sec Civil utility aircraft: 6.692 sec	Airliner: 0.306 sec Civil utility aircraft: 67.885 sec
Installation feasibility	Number of antennas (taking into account redundancy)		2	4	4
Overall link performance	Link margin at max bank angle= (2)	Lat. 65°	ENR: 0 (reference)	ENR: 0dB	ENR: 0dB
		Long. -20°	Bank: 0 (reference)	Bank: 4.3dB	Bank: 4.3dB
		Lat. 65°	ENR: 0 (reference)	ENR: 0dB	ENR: 0dB
		Long. 20°	Bank: 0 (reference)	Bank: 6.2dB	Bank: 6.2dB
		Lat. 45°	ENR: 0 (reference)	ENR: 0	ENR: 0dB
		Long. -20°	Bank: 0 (reference)	Bank: 1.3 dB	Bank: 0.4dB
		Lat. 45°	ENR: 0 (reference)	ENR: 0	ENR: 0dB
		Long. 20°	Bank: 0 (reference)	Bank: 1.3 dB	Bank: 0.4dB

The data on geometrical availability of the link have been obtained by means of visibility analyses performed on antenna aircraft-to- satellite line of sight (LOS) link. These analyses, have been carried out taking into account the real aircraft manoeuvres, with the twofold objective of:

- Evaluate the link geometrical availability, contributing to the overall system availability which may be offered to the aviation end-users.
- Identify the solutions to increase the satellite link geometrical availability, such as suitable system dimensioning coping with real flight conditions, appropriate numbers of antennas on the aircraft and of satellites simultaneously operating.

A sample of 1000 realistic flight trajectories departing and arriving in airports inside the ECAC coverage has been generated in close co-operation with the University of Salzburg through the NAVSIM simulator. The obtained flight trajectories antenna location, antenna field of view, aircraft model and satellite features have been modelled adopting a commercial of the shelf software package simulator. Link visibility and outage times, as well as aircraft antenna-to-satellite elevation angles and aircrafts bank and pitch angles occurrences statistics, have been computed considering aircraft manoeuvres.

Link availability computation over time has been characterized with different aircraft type airliner and civil utility aircraft.

The link budget analyses have been performed with several kinds of UT antennas taking into account specific installation constraints on the aircraft.

Multidimensional link budgets have been performed by considering the aircraft flying over the ECAC service area and crossing the en route (ENR), traffic manoeuvring (TMN) and oceanic remote polar (ORP) aerospace domains. This entails that aircraft manoeuvring with banking angles in the range [0 ÷ 35°] have been considered. In particular, link budget results have been obtained over the ECAC area on a grid of 1° per 1° resolution.

The actual antenna gain value used in link budget analyses has been calculated according to the values of the adopted antenna radiation pattern and taking into account the composition of the:

- The satellite elevation angle associated with the geographical site for the aircraft;
- The banking angle of the aircraft during manoeuvres.

Three cases have been analysed as for the number and position of the antennas on the aircraft:

- One single antenna installed on top of the fuselage.
- Two antennas installed at 45° with respect to the zenith directly above the airframe
- Two antennas, one installed on top of the fuselage and the other installed on bottom part (fill in antenna).

In particular, for each case different types of antenna radiation patterns have been considered referring to possible installation solution.

The values show in Table 5 has been obtained considering the difference of signal to noise ratio (ΔC/N0) on four points of the ECAC area and whereas the mobile terminal during both en route (ENR) at the stage of manoeuvres (TMA). The comparison is carried out using the single antenna case as a reference compared to cases with dual antenna (both 45 ° and 180°).

On the basis of the results, the major conclusion of this trade off on the user terminal configuration, is that the following alternative are selected:

- Single antenna installed on top of the fuselage.
- Two antennas at 45° with respect to the zenith above airframe.

Both alternatives are retained to take into account variable installation and operational conditions of the aircraft.

4 Conclusions

This paper seeks to underline the importance of a system design process defined through a well posed approach that allows to realize a preliminary set of systems architectures when the user requirements are not firmly defined. In order to cope with these uncertainties, a systematic process has been defined by ANTARES system team. A subset of five alternative system architectures has been selected which is highly representative and particularly appropriate to evaluate the impact of requirements variability on the system design. The system design has been performed by identifying a wide set of possible Design Options representing different technical choices. Moreover, considering the user requirements, several options have been analyzed.

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